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# Construction In Space

A Proposed Experiment In Support Of  
The Space Solar Power Concept  
And Other Large Space Systems

March 30, 1977

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PROPOSED EXPERIMENT IN SUPPORT OF THE SPACE  
SOLAR POWER CONCEPT AND OTHER LARGE SPACE  
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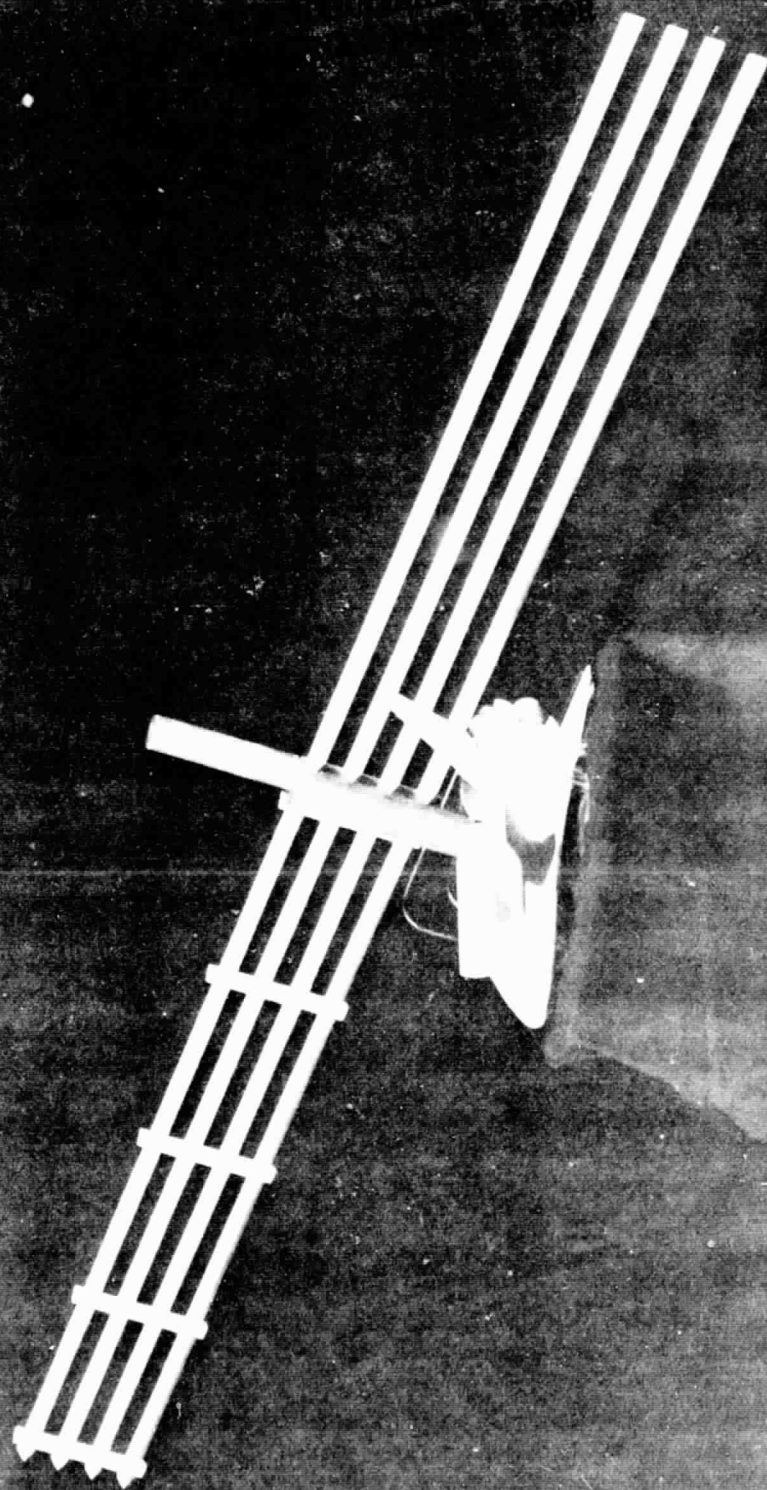
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**NASA**

National Aeronautics and  
Space Administration

**Lyndon B. Johnson Space Center**  
Houston, Texas



CONSTRUCTION EXPERIMENT  
CROSS MEMBERS BEING FABRICATED AND ATTACHED

## **FOREWORD**

Potential space activities such as space solar power stations will require large structures. Because of their large size, these structures must be fabricated, assembled, and/or deployed in space. This brochure describes and illustrates the conceptual equipment and techniques for fabricating and assembling a ladder-like structure of triangular cross section trusses. Such a structure would be suitable for mounting solar cell arrays. The detail information contained herein is presented in the context of a proposed experiment to be conducted from the Shuttle in the 1980-84 time period as an early experiment in the development of techniques for the construction of large space structures that would be required for space solar power stations and other large systems.

## BEAM BUILDER

The beam builder (concept) depicted on the chart continuously and automatically fabricates a triangular cross section truss (dimensions on the order of 1.5 meters on the side) of practically any desired length, from strip material stored on reels. The strip material is processed and wound onto the reels as an earth-based operation, and the beam builder may be "reloaded" with material as often as desired. A likely material is graphite fiber reinforced thermoplastic (such as polysulfone), as is used in this design. The truss consists of three cap members (one at each corner of the triangle) plus side members which interconnect the caps to complete the truss. In operation, a cap is formed as follows: strip material unwinds from the reel and travels through a heating module where it is heated by radiant electric heaters, for example, to its plastic, or forming, temperature (about 600° F). Then it travels through a series of matched rollers which form it from a flat strip to a flanged, triangular shape. As it leaves the last of the forming rollers, it enters a cooling section where its temperature is reduced to the "rigid" state (about 275° F) by radiation to cold plates, for example. Now it is a finished cap, moving through the beam builder to be joined to the side members. The side members are fabricated as follows: material is processed at earth-based facilities into a flat, patterned sheet, as indicated on the illustration, and wound onto a reel (three identical reels of material for the three sides). The material is unwound from the reel, heated in the same manner as the caps, and stiffening beads (the "beads" are not shown in the illustration) are formed into the cross member portions

by a press forming mechanism (which momentarily translates the forming dies to match the velocity of the strip material as it moves through the beam builder). The material is then cooled (radiation to cold plates) and is positioned onto the caps where it is joined by ultrasonic spot welders. (Ultrasonic vibration produces melting of the thermoplastic at the faying surface with subsequent fusion of the surfaces.)

Precise coordination of the velocity of all members is required to fabricate a "straight" truss member and to avoid "buckling" of a cap member, for example, in case that cap is being driven through the forming rollers faster than the other caps.

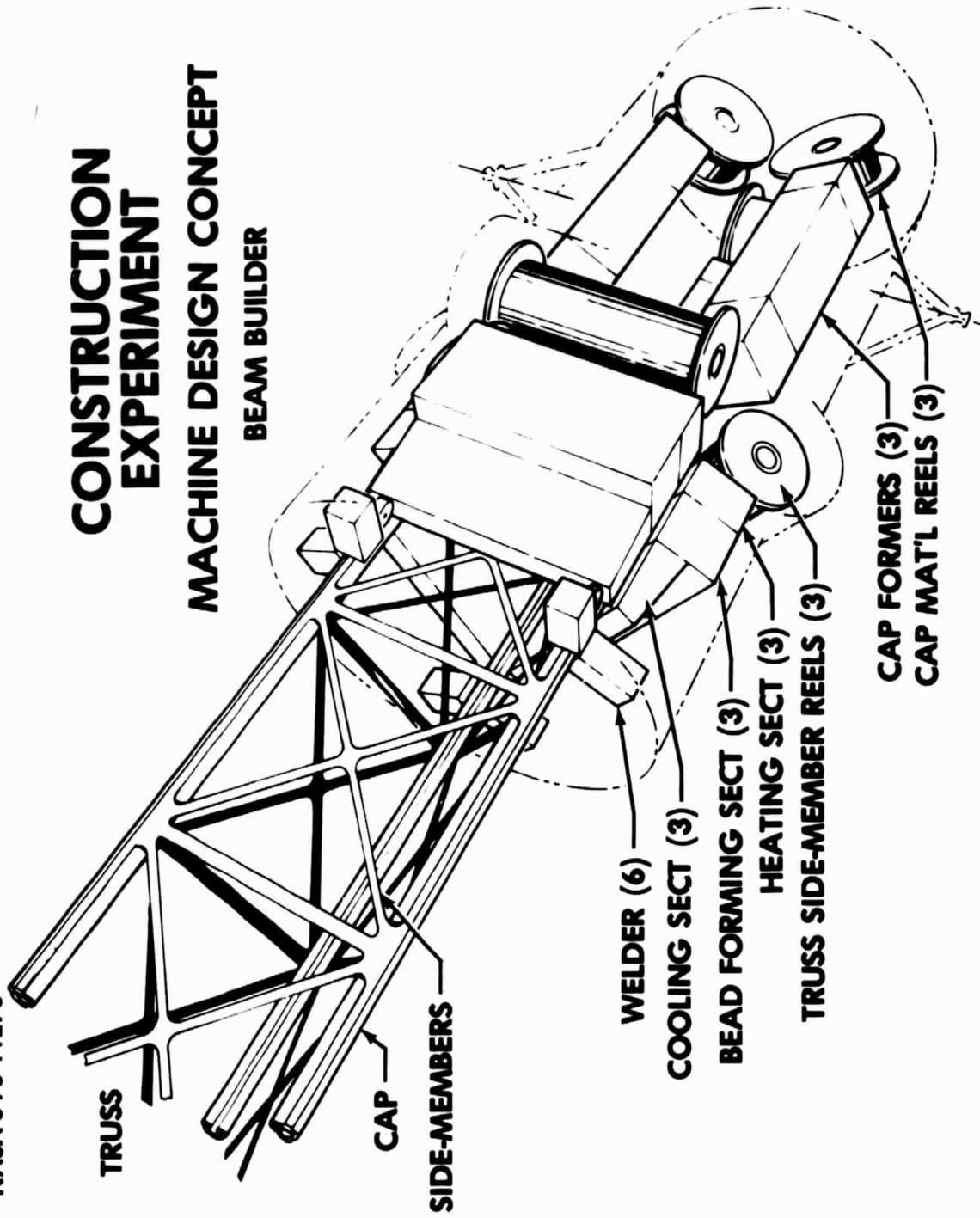
A "closed-loop" type control system employing appropriate sensors, electronics and servo-mechanisms will be employed to control and coordinate the machine operations.

The rate of fabrication may be relatively slow, by commercial standards, to reduce power demands and minimize the weight and size of the beam builder. A fabrication rate of about one inch per second is considered to be appropriate. However, at this slow rate, the machine could fabricate a one-mile long truss in less than 18 hours.

The reel sizes indicated on the drawing are sufficient to fabricate a length of truss in excess on one kilometer, without reloading the beam builder.

# CONSTRUCTION EXPERIMENT

## MACHINE DESIGN CONCEPT BEAM BUILDER



## MACHINE DESIGN-PROCESS OPTIONS

The chart depicts, schematically, several process options that are representative of those that may be utilized by the beam builder to fabricate a truss beam. A primary objective of initial design studies of the beam builder will be to select the appropriate processes, considering the beam configuration to be fabricated, the material to be used for the beam, and the relative merits of the various fabrication processes.

As indicated by the illustration, the cap material stock is likely to be strip which is stored on reels, either multiple reels supplying thin strips which are "laminated" or consolidated into a single, thicker, strip by the beam builder, or a single reel of strip material of the desired thickness. The choice will depend on the desired final thickness and material type and characteristics. For graphite fiber reinforced thermoplastic material, for example, a single reel is a likely choice. In this case, multiple strips of "pre-preg" tape — each with appropriate fiber orientation — consolidated into a single composite strip on Earth.

Three possible cap-forming processes, as indicated, are "spiral tubeform", "roll-form", and "pultrusion". These basic processes are in regular commercial use today. The spiral tubeform process can form a tubular cap member of relatively large diameter from narrow strip by spirally winding the strip and continuously joining the overlapping edges. A fundamental problem with this process for use in the beam builder, however, is that the forming mechanism plus the material supply reel must rotate about the longitudinal axis of the tube. The roll-form process uses mating rollers to continuously bend the flat strip into shape as it passes between the rollers. Multiple rollers, arranged in series so as to form progressively in "stages" are used for complex shapes, each stage of rollers forming a portion of the final shape. Almost any shape, including a closed section such as a tube, can be roll-formed. The pultrusion process uses dies (similar to extrusion dies) through which the flat strip is "pulled" to form the shape. The pultrusion process is most appropriate for thermosetting plastic where heated forming dies produce the formed shape and supply heat to provide the final thermal "cure" of the material.

The sidemembers of the truss beam (crossmembers and diagonals) may also be formed from strip, using the roll-form or pultrusion pro-

cess. A continuously formed section would be periodically cut to the appropriate member length to span between the caps, and a mechanism would position each member for fastening to the caps. Sidemembers could also be preformed on Earth and stored in "clips", from which they would be removed sequentially and assembled into the truss beam by automated mechanisms. The shape of the pre-forms would be selected so that they would stack together, as indicated, in a dense package.

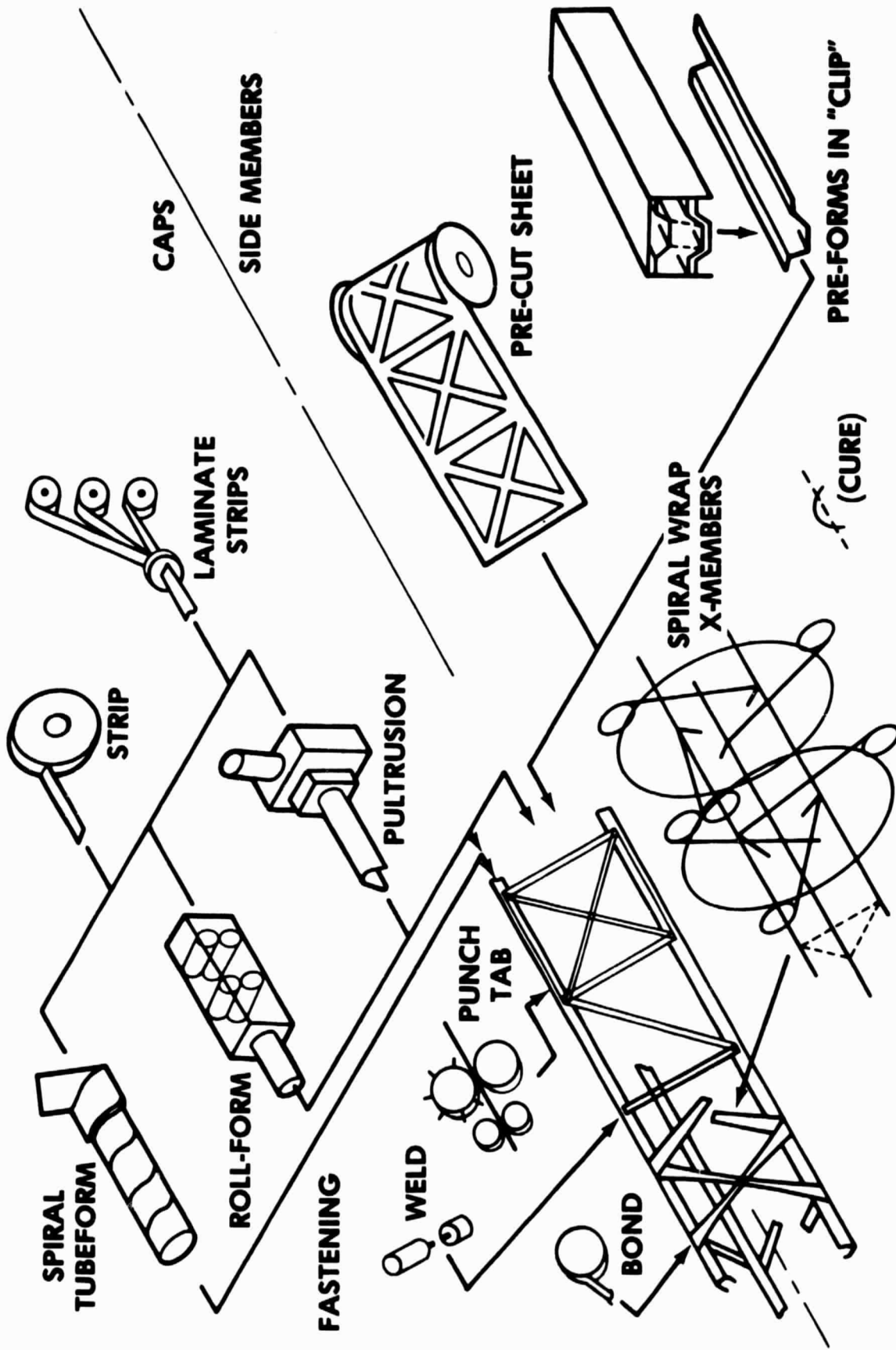
An entirely different process than those previously described for fabrication of truss sidemembers involves spirally wrapping tape around the caps from six reels, as indicated. The tape would be a thermosetting composite which would be designed to thermally cure to a curved cross section shape as indicated, thus being capable of compression loading. Tension diagonals (X-members), may simply be cables or wires fed from supply reels in the spiral wrap manner, or the reels may be fixed and additional mechanisms employed to install the wires in a "back and forth" action between compression crossmembers.

The sidemembers (crossmembers and diagonals) could be integrated in the form of a pre-cut sheet as shown in the illustration. Instead of cutting from a large sheet, the material could be fabricated in the pattern shown, using automated composite material layout machinery similar to that currently used for aircraft structure. Then, during beam builder operation, the sheet is unrolled from its supply reel, stiffening beads or flanges are formed in the appropriate members, and the sheet is joined to the caps.

For fastening the sidemembers to the caps, three appropriate techniques are bonding, welding, and punch tab. The punch tab technique would only be considered for metals, such as aluminum, and involves shearing a small tab from the pieces to be joined and bending it over to form a joint somewhat like a hollow rivet. Welding would likely be resistance spotwelding for metals and ultrasonic spotwelding for thermoplastics. Bonding would involve the application of a tape, activated by heat, between the facing surfaces to be joined. The use of rivets or bolts is not contemplated because of the problem of debris from punched or drilled holes.



# MACHINE DESIGN - PROCESS OPTIONS





## **STRUCTURE FABRICATION SYSTEM CONCEPT FOR LADDER CONFIGURATION (LONGITUDINALS)**

The illustration indicates the use of the beam builder and an "assembly jig" which are carried into orbit in the Space Shuttle Orbiter's payload bay, deployed into operating position—remaining attached to the Orbiter—and used to fabricate a large, lightweight structural assembly (or "platform") with minimum participation by the four-man crew of the Orbiter, within a time frame of one week in orbit.

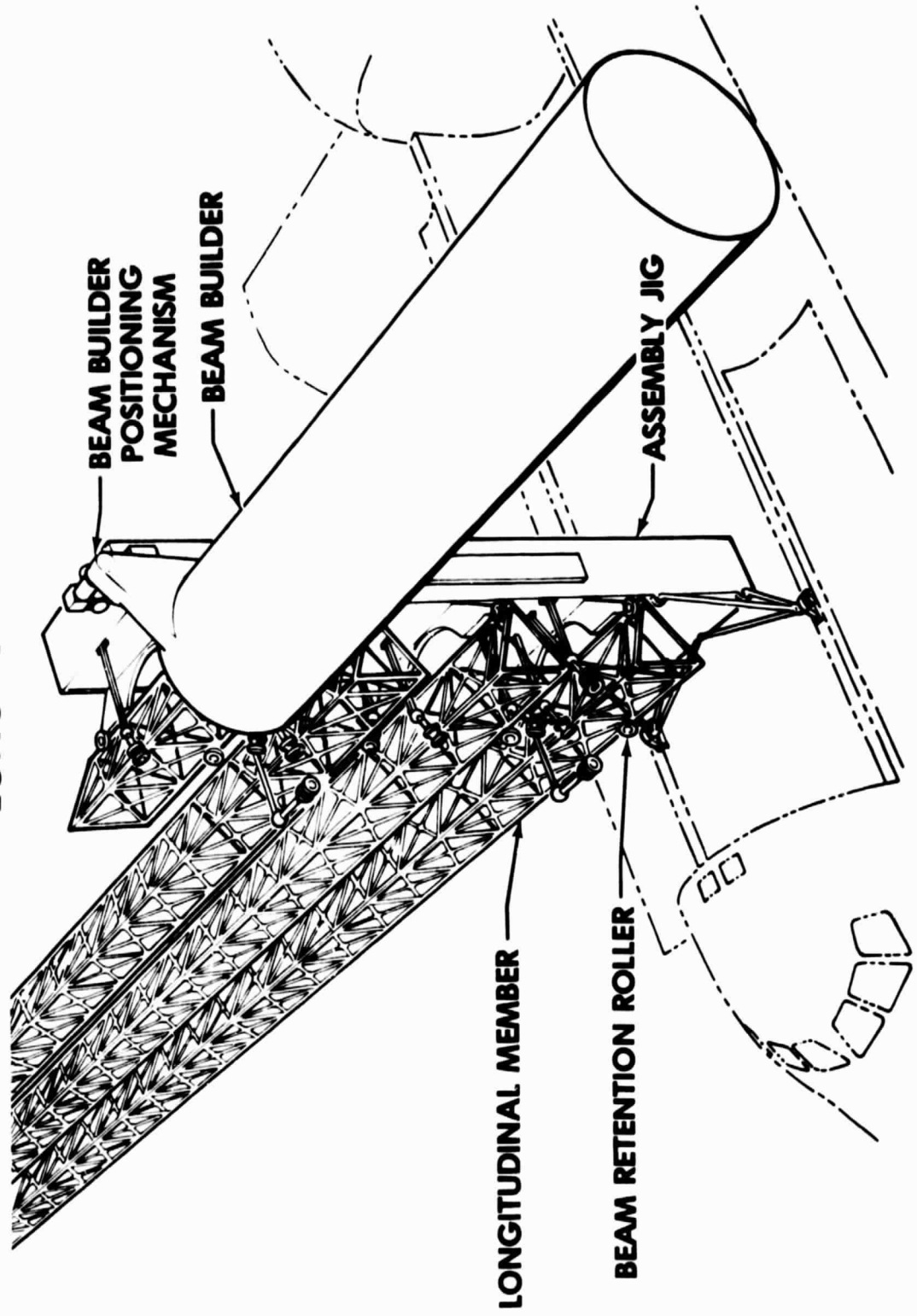
In operation, the beam builder is positioned to fabricate, in sequence, four longitudinal truss members, each 1.5 meters wide and about 200 meters long, and each being fabricated "in situ", such that when completed and cut

off from the beam builder, the assembly jig will grip the beams through a system of rollers, maintaining their relative positions.

In this illustration, the beam builder has just commenced fabrication of the fourth longitudinal. By repositioning the beam builder to fabricate the longitudinals in their proper relative positions, the problem of repositioning the long members, with their very high mass moments of inertia about a transverse axis plus their flexibility, is avoided.

The next illustration depicts the final stage of fabrication.

# STRUCTURE FABRICATION SYSTEM CONCEPT FOR LADDER CONFIGURATION LONGITUDINALS



## **STRUCTURE FABRICATION SYSTEM CONCEPT FOR LADDER CONFIGURATION (CROSSMEMBERS)**

In this illustration, the beam builder is in position to fabricate 10.5-meter-long crossmembers, in situ, with the first crossmember nearing completion. When the first crossmember is completed, it will be cut off from the beam builder and gripped by the assembly jig rollers. Crewmen will then exit from the Orbiter through its airlock and attach the crossmember to the longitudinals by using handheld ultrasonic welders to join two caps of the triangular crossmember truss to the caps of each longitudinal where they cross (four places at each longitudinal). After the first crossmember is attached, the structural assembly will be moved through the jig by driving appropriate rollers to a position for installation of another crossmember about 20 meters from the first. This operation is repeated until nine crossmembers are installed, to complete a structural platform about 10.5

meters wide by 200 meters long. This size is representative of the capabilities afforded by one "standard" shuttle mission.

The crew would be utilized (in extravehicular activities) to attach the crossmembers, inspect the fabrication process close up, and aid in assembly jig setup. Complete automation could be achieved; however, determining the value of the crew operations is an important part of the experiment.

After completion of the platform, various engineering tests and experiments would be performed while it is attached to the Orbiter, and a myriad of subsequent mission operations are possible. The platform would, finally, be released from the jig and the jig and beam builder returned to earth in the Orbiter.

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# STRUCTURE FABRICATION SYSTEM CONCEPT FOR LADDER CONFIGURATION

CROSS MEMBERS

LONGITUDINAL MEMBER

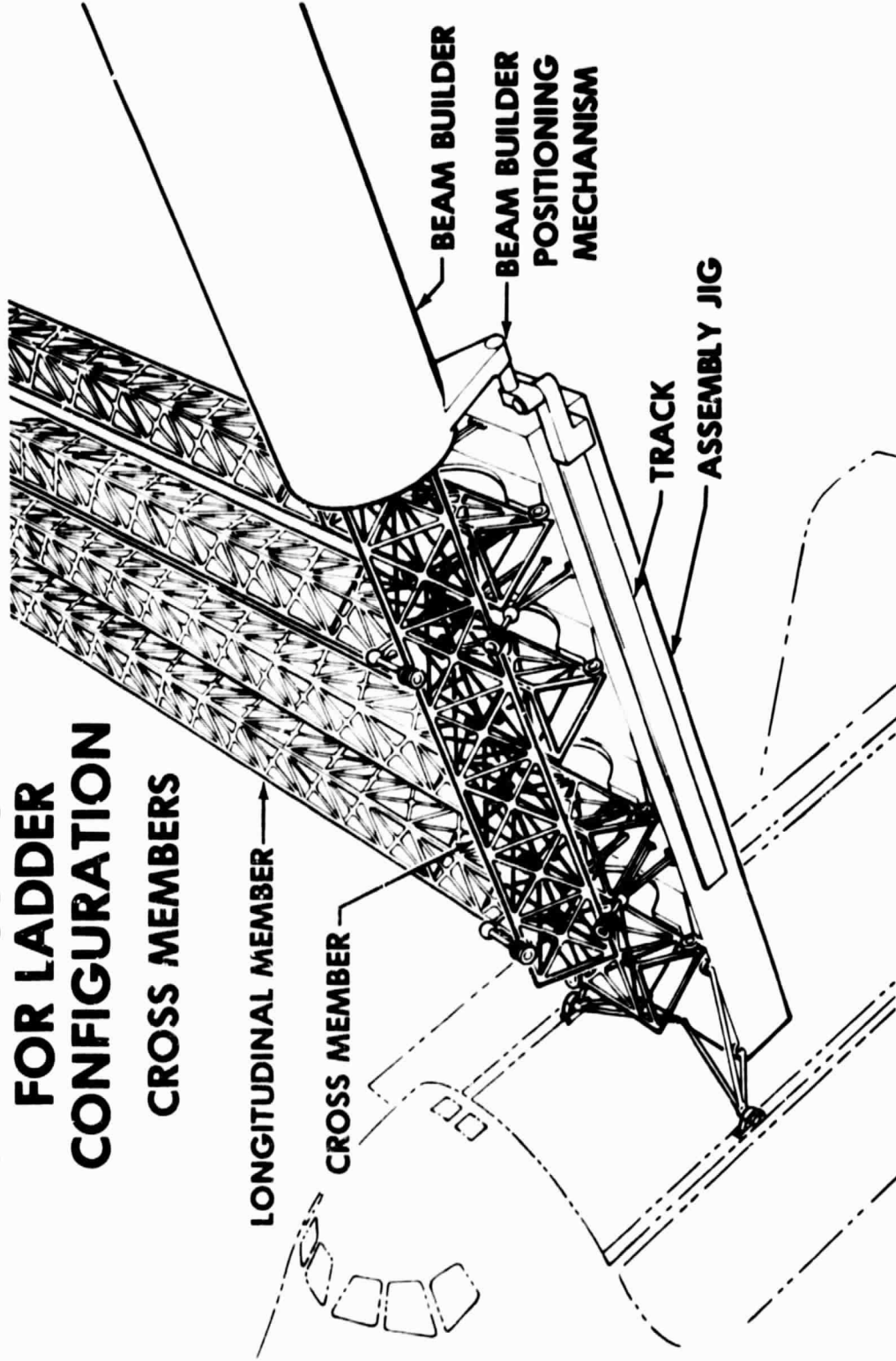
CROSS MEMBER

BEAM BUILDER

BEAM BUILDER  
POSITIONING  
MECHANISM

TRACK

ASSEMBLY JIG



## **FABRICATION SEQUENCE LADDER CONFIGURATION**

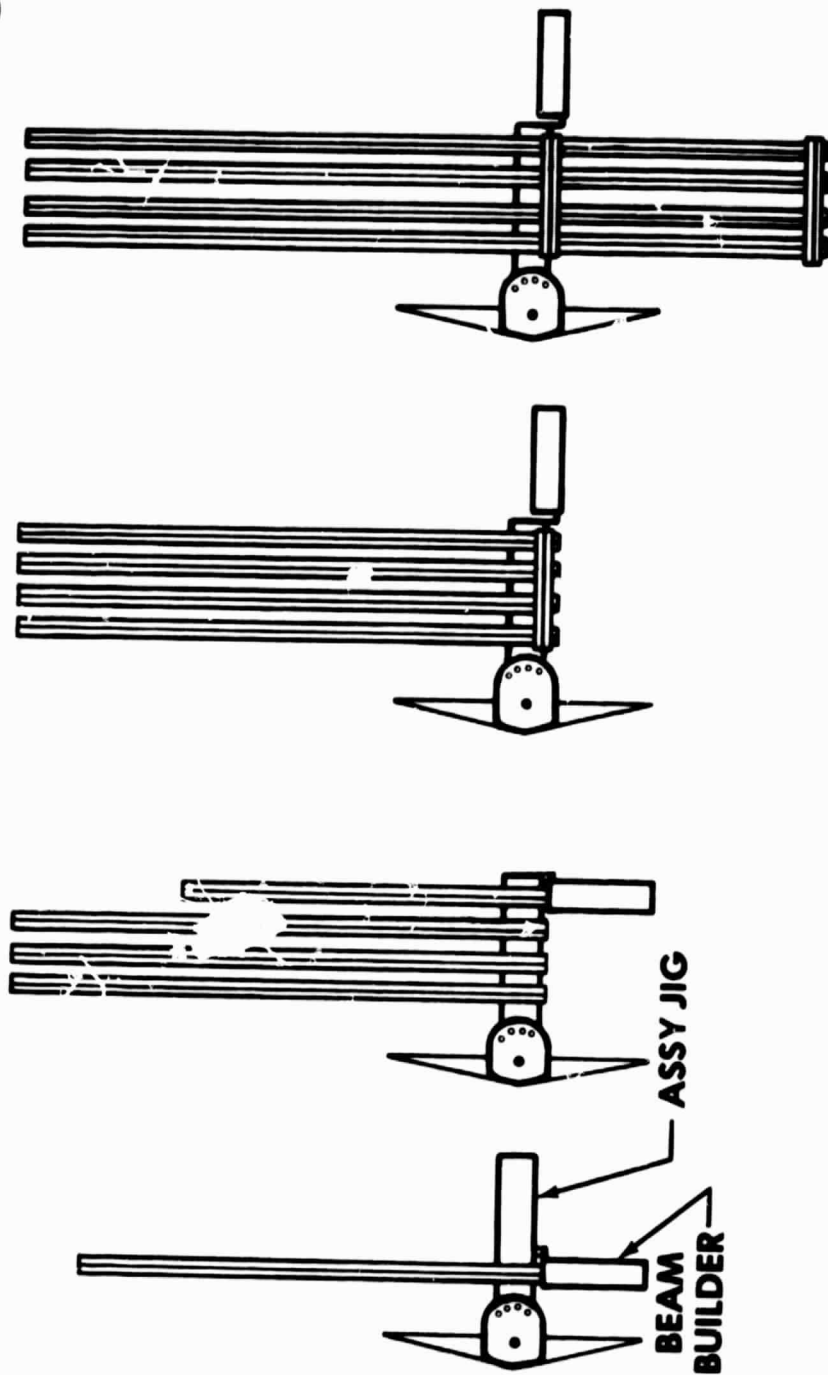
The sequence of fabrication of the structural platform, shown schematically on the chart, is as follows: The beam builder is first positioned relative to the assembly jig as shown in the left-hand view by a positioning mechanism on the jig. It fabricates the first longitudinal beam, to the proper length, and stops operation. The beam is "gripped" by rollers on the assembly jig and the beam builder cuts off the longitudinal beam. Then the beam builder is moved along a track on the side of the assembly jig until it is in position to fabricate the second longitudinal, adjacent and parallel to the first longitudinal, in the same operational manner. This sequence is repeated until the fourth longitudinal is completed.

The beam builder is then rotated into the position to fabricate the first crossmember. After it is completed, the crossmember is joined to the longitudinals by an Orbiter crewman using a portable ultrasonic spotwelder (16 places - where the crossmember and longitudinal beam cap members cross each other).

The partially constructed platform is then driven "across" the assembly jig by the retaining rollers until the longitudinals are in position relative to the beam builder for fabrication and attachment of the second crossmember in the same manner as the first. These events are repeated until installation of the last crossmember, which completes the construction of the platform.

NASA-S-76-11275

# FABRICATION SEQUENCE LADDER CONFIGURATION



|                         |                         |                         |                                  |
|-------------------------|-------------------------|-------------------------|----------------------------------|
| FAB 1ST<br>LONGITUDINAL | FAB 4TH<br>LONGITUDINAL | FAB 1ST<br>CROSS-MEMBER | FAB 2ND<br>CROSS-MEMBER<br>(ETC) |
|-------------------------|-------------------------|-------------------------|----------------------------------|

## **SUBSYSTEM INSTALLATION**

The chart illustrates the installation of subsystems to the structural platform. Modularized equipment assemblies would be carried in the Orbiter payload bay and installed onto the platform, using the Orbiter's remote manipulator system (RMS) to move the equipment assemblies into position, and an Orbiter crewman to make the structural and electrical connections.

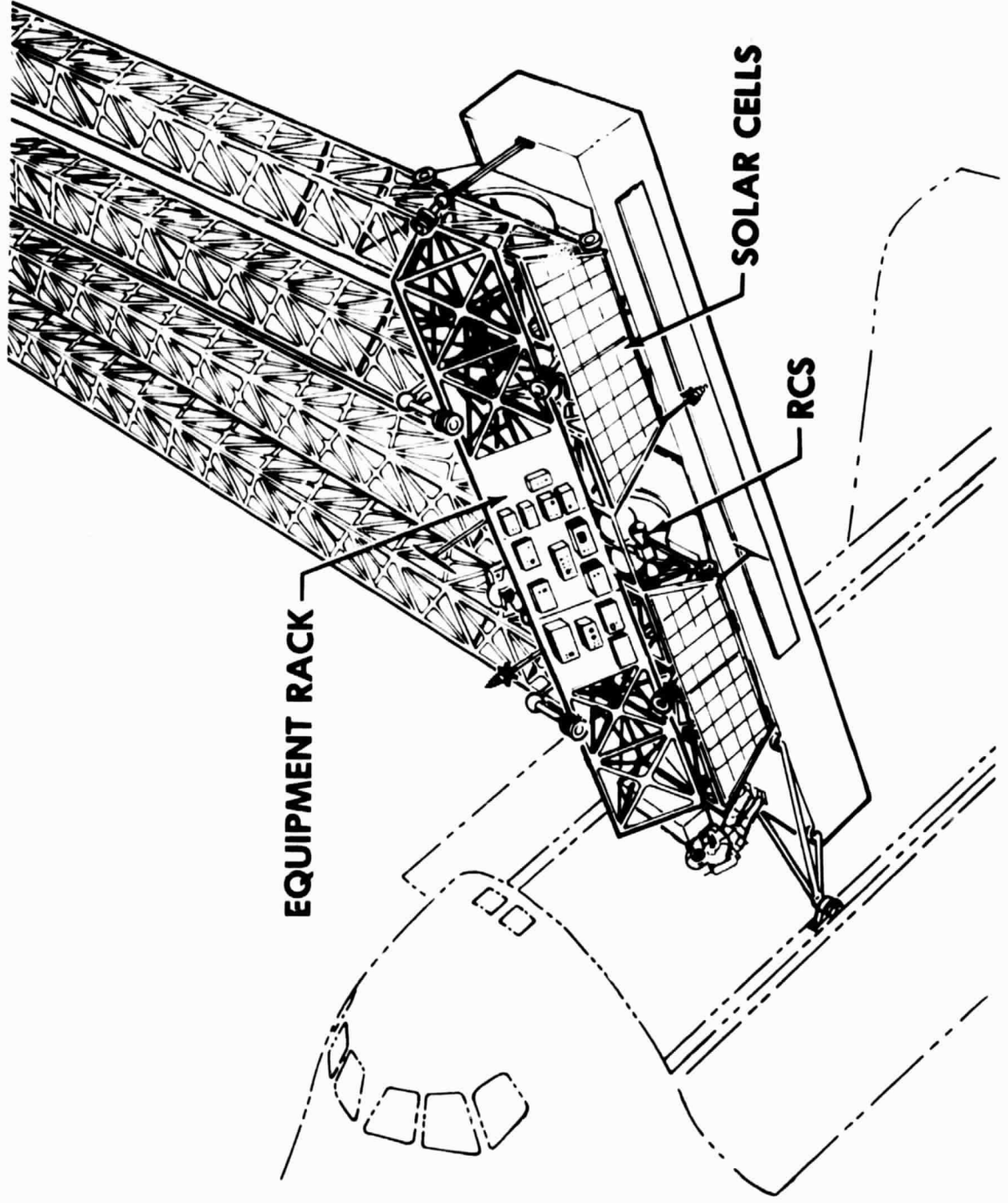
Representative subsystems include reaction control (RCS), solar cells and batteries, communications equipment, experiment equipment and data recorders.

Development of the techniques and design features necessary for equipment installation in space is an important objective of the construction experiment.



NASA-S-76-11274

# SUBSYSTEM INSTALLATION



## MISSION PROFILE

The figure indicates possible significant mission events superimposed on a plot of platform altitude versus time resulting from normal orbital decay (without application of orbit-keeping propulsion). Because of its high drag area relative to its mass, the platform should be constructed at an orbital altitude of approximately 300 nautical miles to insure that it has adequate orbital lifetime for reasonable utilization of its experiment potentialities.

The platform can be constructed, and important structural engineering tests can be performed, utilizing a single Shuttle flight of seven days duration. The platform would be separated from the Orbiter at the end of the seven days and the Orbiter returned to Earth. Subsequently, the platform would be tracked by radar from Earth to determine its actual orbital decay rate. The platform would be in a free-drift attitude mode after separation from the Orbiter, but would tend to align itself along a radius toward the Earth's center due to gravity gradient forces.

A second Shuttle flight is contemplated about six weeks later, wherein the platform is reattached to the assembly jig that was used to construct it on the first flight. The development of the technique and equipment to "dock" the Orbiter to the large, lightweight structural platform is an important mission objective of the second flight -

being a requirement for full utilization of space construction. A wide range of subsequent accomplishments are possible on the second flight. For example, solar cell "blankets" could be installed on the platform to create a space solar power test bed. Reaction control systems could be added, to investigate the technology of attitude control and propulsion of large, relatively flexible structural assemblies. Special equipment could be installed to perform experiments utilizing the unique, large size of the platform, and its rapid orbital decay rate. The mission profile indicates two such experimental possibilities, the geodynamics and atmospheric composition experiments. For the geodynamics experiment, the platform's orbital attitude is very accurately tracked from the ground and a satellite in synchronous orbit, resulting in more accurate knowledge of the Earth's mass distribution. For the atmospheric composition experiment, a laser emitter and reflector are installed at opposite ends of the platform and the platform is set into rotation by the reaction control system. During the subsequent orbital decay period, the laser device obtains data that allow determination of the atmospheric composition from that initial altitude until entry into the lower atmosphere.

During atmospheric entry, the platform will be entirely "burned", due to its large area, low weight characteristics, constituting no hazard to the Earth's surface.

# MISSION PROFILE

